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COMPREHENSIVE ANALYSIS OF ENERGY AUDIT STRATEGIES FOR ENHANCING ENERGY EFFICIENCY IN HIGHER EDUCATIONAL INSTITUTES

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ABSTRACT

Increasing demand of energy and associated cost create considerable significance for energy conservation and energy audit. Energy audit creates opportunities to improve energy efficiency and to reduce energy cost. Authors looked into and peer reviewed energy audit technical articles to find innovative approaches for energy efficiency improvement, including methodologies employed, findings and future work for the energy audit case studies of educational institutes. The review shows that most articles emphasis on the lighting load during energy audits of higher educational institutes. In this paper, the authors have discussed the identified areas with energy conservation potential for the higher educational institute in Saurashtra region of Gujarat, India.

I. INTRODUCTION

In modern world, energy is a prime input for almost all the activities taking place around us. Therefore, energy availability crates a prime importance. India has installed capacity of electricity generation 452.69 GW, with renewable and non-renewable power mix, and still fossil fuel based non-renewable energy generation capacity is of 249.51 GW (53.7%) as on November 2024 [1]. Total emission due to non-renewable energy generation of Indian power sector is 1,091.96 million tonnes of CO2 [2]. Carbon emission creates adverse effect on environment and health. This is creating prime concern for energy conservation. Energy Conservation Act, 2001 is an important step by Government of India to provide legislative framework to energy efficiency related activities. Energy audit is a systematic process to assess energy usage of an institute and get familiar with energy conservation opportunities. Through energy audit areas of inefficiency may be identified and measures may be proposed for energy efficiency improvement.

Implementation of these measures attract various advantages shown in Figure 1 for the organization [3]. The authors have found potential for energy conservation through energy audit at a higher educational institute located at Rajkot, Gujarat, India. Authors observed enormous amount of energy consumption at the institute and willing to identify the reasons and sources of energy wastage, if any through energy audit. As background work, authors have reviewed several research articles to understand methodologies and outcomes of energy audits. This research paper provides a comprehensive analysis of Energy Conservation Measures (ECMs) included by authors in the listed research articles to improve energy efficiency and reduce energy costs. Implementation of suggested measures may help to reduce carbon footprint and help the organization to comply with statutory regulations and standards for an educational institute. By fostering a deeper understanding of energy efficiency and conservation, this review contributes to the ongoing efforts to create more sustainable and environmentally responsible institutions.

Figure 1: Advantages efficiency improvement through Energy Audit.
Source: Authors, (2026).

Authors of one of the reviewed article have suggested scope 1, scope 2 and scope 3 carbon emission calculations as per ISO 14064 Green House Gas (GHG) protocol, which is carried out for an educational campus with small sample size for two intervals, April 2019 to March 2020 and April 2021 to March 2022. In the context of this [4]:

1. For scope 1 emission calculation, authors considered quantity of LPG used and petrol & diesel consumption in vehicles rented or owned by the institute. Authors have shown 74.61 and 27.11 tCO2e scope 1 emission for said intervals respectively.
2. For scope 2 emission calculation, electricity consumption of 72 quarters is considered. It is 3,495 and 2,688 tCO2e for said intervals respectively, with an assumption that 250 units of electricity is consumed by every house, every month.
3. For scope 3 emission calculations, carbon emission due to air travel of students & teachers and due to wet waste composting is considered, which is 1,090 and 48 tCO2e for said intervals respectively. Also, authors have calculated carbon offset by natural sink-trees, which is 23 and 33 tCO2e for said intervals respectively.

This paper serves as an important reference for implementing GHG assessments at higher education institutions. However, it has the following limitations:

1. Authors have not commented on diesel consumption of standby energy source (Diesel Generator). Carbon emission due to diesel consumption must be taken in considered while accounting scope 1 emission.
2. Actual electricity consumption must be considered while accounting scope 2 emission.
3. More indirect sources of carbon emission must be considered for scope 3 emission accounting.

Authors of one of the reviewed articles have suggested partial implementation of Energy Conservation Building Code (ECBC) to reduce energy use. With this suggestion, damaged windows are to be replaced with efficient glazed windows. This glazing may reduce the electrical AC load as it is rejecting almost 78% of solar radiance incidence on the window. Also, authors have suggested to replace classical ceiling fans of 70-80 W with Brushless DC (BLDC) fan of 25-30 W, to replace existing lights with LED lights, up-gradation of cooling tower fans and air handling units by installing variable speed drives, installation of solar photovoltaic system and usage of high solar reflectivity index paints for walls. Also, authors have suggested applying low emissivity film on windows to reduce heat transmission without affecting quantity of light passing through it. Authors have shown annual energy saving of 34.8% in cooling load, 28.1% in ventilation load and 27.8% in lighting load with these energy conservation measures for the proposed system [5]. A notable limitation of this article is that the use of automation tools with lighting fixtures could significantly reduce energy consumption and associated costs. Authors of a reviewed article have emphasized on impact of occupant behavior on energy consumption of heating & ventilation system for building of a housing society. Authors have also evaluated Energy Performance Gap (EPG) due to inefficiency of the system and occupant behavior [6].

Authors of one of the reviewed articles have emphasized on boiler performance from thermal efficiency aspect of the system. The authors have suggested various ECMs like adjustment of air-fuel ratio, economizer fitting, trapping steam leakage & its removal and installation of pre-heater for optimum efficiency of the boiler. For each ECM, authors have evaluated annual thermal energy saving, annual fuel saving, annual cost saving, implementation cost and simple payback period. Installation of bio-gas plant is also suggested to reduce running cost of the brewery. Authors have shown Annual thermal energy saving of 22,756,696 MJ, Annual fuel saving of 590,345 liter, Annual cost saving of 6,525,000 Birr by implementing said ECMs. Authors have also accounted carbon footprint of the brewery and had shown potential for significant decrease in it through renewable energy & efficiency measures [7]. A drawback of this paper is that the authors have not provided details on the emission factor. Including this information would make it easier for readers to understand the carbon footprint calculations. Authors of a reviewed article have observed maximum demand variation and power factor variation for year 2021 and 2022 of LBS college of Engineering. Total load connected for various buildings and departments is 469.173 kW. Authors have suggested following practices in the context of ECM [8]:

1. Replacement of 40W fluorescent tube lights with 20W LED, this accounts power saving of 17.8 kW or 50 % with payback period of 11 months for the investment to be done.
2. Replacement of 60W incandescent lamps with 9W LED bulbs, this accounts power saving of 3.1 kW or 85% with simple payback period of 1 month for the investment to be done.
3. Replacement of 60W ceiling fans with 30W BLDC fans, this accounts power saving of 24.75 kW or 50% with simple payback period of 6 years 6 months.
4. Power factor improvement by addition of 26 kVAR capacitor bank. This accounts 7.33 kVA reduction in kVA demand, annual savings of INR 36,960 and payback period of 4 months.
5. Feasibility of biogas plant is justified by demonstrating payback period of 1 year 1 month due to energy and associated cost saving of INR 491,040 or saving of 20 cylinders or 38% of LPG monthly.

Authors of one of the reviewed articles have considered lighting system and air conditioning (AC) system for energy conservation for an educational institute of Bangladesh. Authors ‘contributions in the context of ECM, are as follows [9]:

1. Authors have suggested to replace T5 Linear Fluorescent Lamp (LFL), T8 LFL and fluorescent lamps with energy efficient lamps of 18 W and accounted the power saving of 1,744 W, 6.0616 MWh annual energy with payback period of 2.1 years for the investment to be done. This ECM accounts 38.6% saving in power.
2. Authors observed that oversized non star rated Air Conditioners (ACs) are in use than required. Power saving of 85.5 kW is shown by selecting proper size AC units. This ECM accounts 75% saving in power. Also, payback period of 8 years is calculated for replacement of existing AC with 3-star rated AC units [9].

A reviewed article considered lighting system, fan and water heating system for energy conservation opportunities, residential hall of a university. Following are the findings of the authors in the context of ECM [10]:

1. Authors have shown 50%, 87% and 47.5% potential energy saving by replacing CFL, incandescent bulb and fluorescent tube respectively by LED bulbs or LED tubes with payback period of 50 days, 7 days and 34 days respectively.
2. Authors have shown 37.5% potential energy saving by replacing inefficient fans by 5-star rated fans, with 1.3 years payback period.
3. Authors have shown 50% potential energy saving by using automation with water heater. Authors have shown payback period of 2 days for it.
4. Authors have calculated reduction in CO2 emission of 66.5 MT due to implementation of ECMs.

II. METHODOLOGY

To address the problem of enormous amount of energy consumption and associated cost at the higher educational institution, authors found fields which require attention in context to trap energy wastage or to enhance energy efficiency. This may lead the institute to be more energy intensive.

1. Energy usage analysis activity provides elementary information about how energy consumption pattern is, energy cost, seasonal effect on energy consumption, rebate and/or penalty, if applied. This may be gained from detailed examination of energy bills.
2. Lighting system audit and ventilation system audit creates significant weightage as a part of energy audit for educational institute, as lighting and ventilation load covers majority part of the load distribution area.
3. Computer laboratories, library and offices of the institute are air-conditioned. These utilities create a considerable burden on electrical system. Almost 13% area of the institute is air-conditioned as shown in Table 1. Thermal system assessment can provide exposure to inefficiencies of Heating, Ventilation & Air-Conditioning (HVAC) system with considerable energy conservation opportunities.

Table 1: Details of Air Conditioned Area.

Particular	Value
Total Air-Conditioned Area	**12,811 m^2**
Built-up Area (excluding parking area)	**97,500 m^2**
Parking Area	**8,926 m^2**
Total Built-up Area	**106,426 m^2**
% Total Air Conditioned Area	**13.14%**

Source: Authors, (2026).

4. Poor power quality can cause damage to electrical equipment, reduce the efficiency of electrical systems. It can also attract penalty for the institute from energy supplying utility. In this context, power quality check including power factor, voltage stability and harmonic analysis may be part of study.
5. Water pumps actually contribute for considerable energy consumption. Hence, Water pumping system assessment is essential to evaluate its performance.
6. Though the institute is in no load shedding region of Gujarat and hence the usage of diesel generator for power generation is very limited, diesel generator performance assessment may disclose finite energy conservation opportunities.
7. The institute has installed PV rooftop generation capacity of 499.2 kW, with solar panels at 4 locations in the institute. PV performance analysis may reveal some energy conservation opportunities.
8. GHG accounting may create knowledge about carbon footprint of the institute. GHG accounting activity can be part of the study.

9. ECBC is a vital tool for promoting energy efficiency in the building sector. Its implementation leads to significant environmental, economic, and social benefits, contributing to sustainable development and improved quality of life. ECBC application for the institute will display energy conservation definitely.

III. RESULTS AND DISCUSSION

The authors will emphasis on following activities to lookout for energy conservation at the institute as shown in Figure 2.

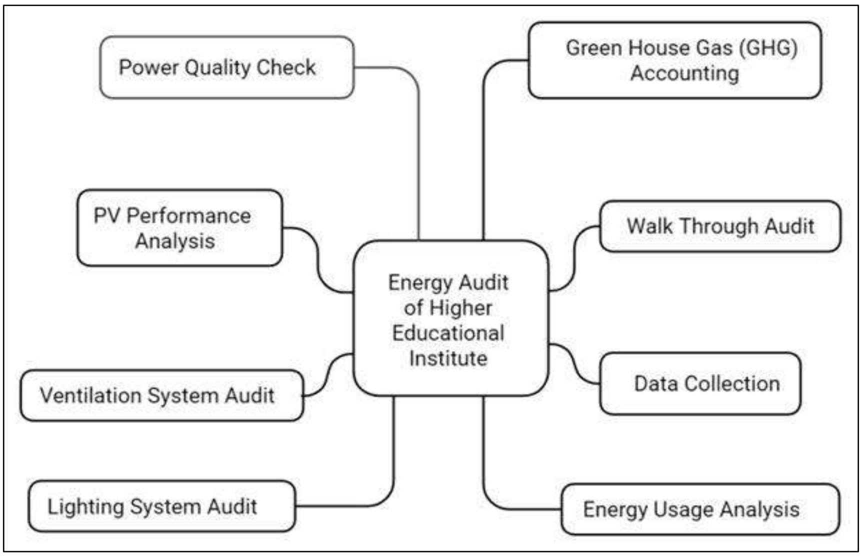

Figure 2: Proposed Methodology.
Source: Authors, (2026).

1. Walk-through audit: It is a very important and primary step in process of energy audit. It gives visual idea of every electrical installation of the institute and provides superficial insights about areas where energy is being wasted and offers practical, often low-cost solutions for immediate savings.
2. Data Collection: It includes collection of electricity bills, electrical equipment specifications and operational details.
3. Energy Usage Analysis: This includes study of current energy consumption details. Also, authors are intended to suggest energy cost saving opportunities with pay-back period calculation in case of investment, if required.
4. Lighting System Audit: This includes the analysis of energy consumption of indoor & outdoor lighting system. Also, comparisons of energy consumption of lighting system with & without ECM, if any, is also to be included. Calculation for economics of ECM applied will also be performed.
5. Ventilation System Audit: This includes the analysis of energy consumption in ventilation system. Also, comparisons of energy consumption of ventilation system with & without ECM, if any, is also to be included. Calculation for economics of ECM applied will also be performed.
6. PV Performance Analysis: This includes the analysis of the rooftop geid-tied PV system.
7. Power Quality Check: Using power analyser, power quality testing is included. This part involves measurement of harmonic levels with supply, voltage fluctuations and power factor. This part includes corrective action in this context, if required, with its economics.
8. GHG Accounting: This includes scope 1, scope 2 and scope 3 carbon emission calculations.

V. CONCLUSION

Authors have observed enormous amount of energy consumption at a higher educational institute located in Gujarat, India. Authors found different fields like energy usage analysis, lighting system audit, ventilation system, power quality check, HVAC system, water pumping system, diesel generator performance, PV performance analysis, GHG accounting, and application of Energy Conservation Building Code, with energy conservation potential. Authors will address many of the above-mentioned fields to cater the problem of high consumption of the energy at the institute.

VI. AUTHOR’S CONTRIBUTION

Conceptualization: Seema V. Vachhani and Dr. Dharmesh J. Pandya.
Methodology: Seema V. Vachhani and Dr. Dharmesh J. Pandya.
Investigation: Seema V. Vachhani.
Discussion of results: Seema V. Vachhani and Dr. Dharmesh J. Pandya.
Writing – Original Draft: Seema V. Vachhani.
Writing – Review and Editing: Seema V. Vachhani and Dr. Dharmesh J. Pandya.
Resources: Seema V. Vachhani and Dr. Dharmesh J. Pandya.
Supervision: Dr. Dharmesh J. Pandya.
Approval of the final text: Seema V. Vachhani and Dr. Dharmesh J. Pandya.

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